

CLAIMS

1. A gait generating device for generating a desired gait of a legged mobile robot that travels by moving a plurality of legs extended from its body, comprising:

5       permissible range setting means for setting a permissible range of a restriction object amount, the restriction object amount being a vertical component of a floor reaction force moment or a component of the floor reaction force moment in floor surface normal line direction, or a vertical component of an angular momentum changing rate of the robot or a component of the angular momentum changing rate in floor surface normal line direction, to be applied to the robot;

10       provisional instantaneous value determining means for determining a provisional instantaneous value of a desired motion constituting the desired gait;

15       model calculating means for supplying at least a provisional instantaneous value of the desired motion to a dynamic model that indicates a relationship between a motion of the robot and the restriction object amount so as to determine an instantaneous value of a model restriction object amount as an output of the dynamic model; and

20       desired instantaneous value determining means for determining an instantaneous value of a desired motion by correcting the provisional instantaneous value of the desired motion such that at least the instantaneous value

of the model restriction object amount falls within the permissible range.

2. The gait generating device of a legged mobile robot according to Claim 1, wherein the desired instantaneous 5 value determining means determines an instantaneous value of a floor reaction force moment that corresponds to a restriction object amount that substantially balances with the instantaneous value of the desired motion on the dynamic model as an instantaneous value of a desired floor 10 reaction force moment constituting the desired gait.

3. The gait generating device of a legged mobile robot according to Claim 1, wherein the desired instantaneous 15 value determining means comprises:

    a perturbation model representing a relationship between a perturbative motion of the robot and a perturbation portion of a restriction object amount; 20  
    means for determining a perturbation model manipulated variable for manipulating the perturbation portion of the restriction object amount of the perturbation model on the basis of at least the instantaneous value of a model restriction object amount determined by the model calculating means and the permissible range;

    means for determining a correction amount of the 25 desired motion by supplying the determined perturbation model manipulated variable to the perturbation model; and  
    means for determining an instantaneous value of the

desired motion by correcting the provisional instantaneous value of the desired motion on the basis of the correction amount.

4. The gait generating device of a legged mobile robot  
5 according to Claim 3, wherein the means for determining  
the perturbation model manipulated amount comprises means  
for determining an estimated value of the restriction  
object amount when it is assumed that the perturbation  
model manipulated amount is zero on the basis of at least  
10 an instantaneous value of a model restriction object  
amount determined by the model calculating means, and  
means for comparing the determined estimated value with  
the permissible range to determine a restricted  
restriction object amount that has been restricted to fall  
15 within the permissible range on the basis of the  
comparison, wherein the perturbation model manipulated  
variable is determined on the basis of at least the  
difference between the instantaneous value of the model  
restriction object amount determined by the model  
20 calculating means and the restricted restriction object  
amount.

5. The gait generating device of a legged mobile robot  
according to Claim 3, further comprising means for  
determining a required value of the perturbation model  
25 manipulated variable on the basis of at least a state  
amount of the perturbation model,  
wherein the means for determining the perturbation

model manipulated variable determines a perturbation model manipulated variable to be supplied to the perturbation model on the basis of at least an instantaneous value of a model restriction object amount determined by the model 5 calculating means, the permissible range, and the required value.

6. The gait generating device of a legged mobile robot according to Claim 5, wherein the means for determining a required value of the perturbation model manipulated 10 variable sequentially determines the required value according to a feedback control law based on a deviation between a state amount of the perturbation model and a desired value for the state amount.

7. The gait generating device of a legged mobile robot 15 according to Claim 5, wherein the means for determining the perturbation model manipulated variable comprises means for determining an estimated value of the restriction object amount when it is assumed that the perturbation model manipulated variable has been matched 20 with the required value on the basis of at least an instantaneous value of a model restriction object amount determined by the model calculating means and the required value, and means for comparing the determined estimated 25 value with the permissible range to determine a restricted restriction object amount that has been restricted to fall within the permissible range on the basis of the comparison, wherein the perturbation model manipulated

variable is determined on the basis of at least the difference between the instantaneous value of the model restriction object amount determined by the model calculating means and the restricted restriction object amount.

5

8. The gait generating device of a legged mobile robot according to Claim 4 or 7, wherein the desired instantaneous value determining means determines an instantaneous value of a floor reaction force moment corresponding to the restricted restriction object amount as an instantaneous value of a desired floor reaction force moment constituting the desired gait.

10

9. The gait generating device of a legged mobile robot according to Claim 4 or 7, wherein the desired instantaneous value determining means comprises means for additionally supplying a correction amount of the desired motion to the dynamic model.

15

10. The gait generating device of a legged mobile robot according to Claim 9, wherein the desired instantaneous value determining means determines an instantaneous value of a floor reaction force moment corresponding to the restricted restriction object amount as an instantaneous value of a desired floor reaction force moment constituting the desired gait.

20

25 11. The gait generating device of a legged mobile robot according to Claim 3, wherein the perturbation model is a model representing a relationship between a perturbative

motion for perturbating a vertical component or a component in floor surface normal line direction of an angular momentum changing rate of the robot and the perturbation portion of a restriction object amount.

5       12. The gait generating device of a legged mobile robot according to Claim 11, wherein the perturbative motion is a perturbative motion for maintaining the center-of-gravity position of the robot substantially constant.

10      13. The gait generating device of a legged mobile robot according to Claim 11 to 12, wherein the perturbative motion is a perturbative motion of a body of the robot and/or an arm extended from the body.

15      14. A gait generating device for generating a desired gait of a legged mobile robot that travels by moving a plurality of legs extended from its body, comprising:

20        permissible range setting means for setting a permissible range of a restriction object amount, the restriction object amount being a vertical component of a floor reaction force moment or a component of the floor reaction force moment in floor surface normal line direction, or a vertical component of an angular momentum changing rate of the robot or a component of the angular momentum changing rate in floor surface normal line direction, to be applied to the robot;

25        desired floor reaction force provisional instantaneous value determining means for sequentially determining a provisional instantaneous value of at least

a desired floor reaction force among a desired motion and a desired floor reaction force constituting the desired gait;

5       first model calculating means for supplying at least a provisional instantaneous value of the desired floor reaction force to a first dynamic model that indicates a relationship between a motion of the robot and a floor reaction force so as to determine a provisional instantaneous value of a desired motion as an output of  
10      the first dynamic model;

15      second model calculating means for supplying at least a provisional instantaneous value of the desired motion to a second dynamic model that indicates a relationship between a motion of the robot and the restriction object amount so as to determine an instantaneous value of a model restriction object amount as an output of the second dynamic model; and

20      first model input correcting means for determining a floor reaction force moment correction amount of a desired floor reaction force such that at least the instantaneous value of the model restriction object amount falls within the permissible range, and for additionally supplying the determined floor reaction force moment correction amount to the first dynamic model,

25      wherein a desired instantaneous value of the desired motion is determined on the basis of at least an input of the second dynamic model.

15. The gait generating device of a legged mobile robot  
according to Claim 14, further comprising means for  
determining an instantaneous value of a floor reaction  
force moment that substantially corresponds to the  
5 instantaneous value of the model restriction object amount  
output by the second dynamic model as an instantaneous  
value of a desired floor reaction force moment  
constituting the desired gait.

16. The gait generating device of a legged mobile robot  
10 according to Claim 14, wherein the first model input  
correcting means comprises means for estimating, on the  
basis of at least an instantaneous value of a model  
restriction object amount determined by the second model  
calculating means, an estimated value of an instantaneous  
15 value of a model restriction object amount output by the  
second dynamic model if it is assumed that at least a  
floor reaction force moment correction amount of the  
desired floor reaction force is zero, and means for  
comparing the estimated value of an instantaneous value of  
20 the model restriction object amount with the permissible  
range to determine a restricted restriction object amount  
that has been restricted to fall within the permissible  
range on the basis of the comparison, wherein the floor  
reaction force moment correction amount is determined on  
25 the basis of at least the difference between the  
instantaneous value of the model restriction object amount  
determined by the second model calculating means and the

restricted restriction object amount.

17. The gait generating device of a legged mobile robot according to Claim 14, further comprising means for determining a required value of a floor reaction force 5 moment correction amount of the desired floor reaction force, wherein

the first model input correcting means comprises means for estimating, on the basis of at least an instantaneous value of a model restriction object amount determined by the second model calculating means and the required value, an estimated value of an instantaneous value of a model restriction object amount output by the second dynamic model if it is assumed that at least a floor reaction force moment correction amount of the 15 desired floor reaction force is matched to the required value, and means for comparing the estimated value of an instantaneous value of the model restriction object amount with the permissible range to determine a restricted restriction object amount that has been restricted to fall 20 within the permissible range on the basis of the comparison, wherein the floor reaction force moment correction amount is determined on the basis of at least the difference between the instantaneous value of the model restriction object amount determined by the second 25 model calculating means and the restricted restriction object amount.

18. The gait generating device of a legged mobile

robot according to Claim 14, further comprising a second model input correcting means for determining a correction amount of the desired motion on the basis of at least an instantaneous value of a model restriction object amount determined by the second model calculating means and the permissible range, and additionally supplying the determined correction amount to the second dynamic model.

19. The gait generating device of a legged mobile robot according to Claim 18, comprising:

10        a perturbation model representing a relationship between a perturbative motion of the robot and a perturbation portion of a restriction object amount; means for determining a manipulated variable of a floor reaction force moment on the basis of at least an instantaneous value of a model restriction object amount determined by the second model calculating means and the permissible range; and

15        dividing means for dividing the determined manipulated variable of a floor reaction force moment into a floor reaction force moment correction amount of the desired floor reaction force to be supplied to the first dynamic model and a perturbation model manipulated variable to be supplied to the perturbation model,

20        wherein the second model input correcting means supplies the perturbation model manipulated variable to the perturbation model so as to determine a correction amount of the desired motion.

20. The gait generating device of a legged mobile robot according to Claim 19, comprising:

means for determining a required value of a manipulated variable of the floor reaction force moment on the basis of at least a state amount of the perturbation model,

wherein the means for determining a manipulated variable of the floor reaction force moment determines a manipulated variable of a floor reaction force moment to be supplied to the dividing means on the basis of at least the instantaneous value of the model restriction object amount determined by the second model calculating means, the permissible range, and the required value.

21. The gait generating device of a legged mobile robot according to Claim 20, wherein the means for determining the required value of the manipulated variable of a floor reaction force moment sequentially determines the required value according to a feedback control law on the basis of a deviation between the state amount of the perturbation model and a desired value for the state amount.

22. The gait generating device of a legged mobile robot according to Claim 19, wherein the perturbation model is a model representing a relationship between a perturbative motion perturbing a component about a vertical axis or a floor surface normal line axis of an angular momentum changing rate of a robot and a perturbation portion of the restriction object amount.

23. The gait generating device of a legged mobile robot according to Claim 22, wherein the perturbative motion is a perturbative motion for maintaining the position of a center-of-gravity of the robot substantially constant.

5 24. The gait generating device of a legged mobile robot according to Claim 23 or 23, wherein the perturbative motion is a perturbative motion of a body of the robot and/or an arm extended from the body.

10 25. The gait generating device of a legged mobile robot according to Claim 19, wherein the means for determining a manipulated variable of the floor reaction force moment comprises means for estimating, on the basis of at least an instantaneous value of a model restriction object amount determined by the second model calculating means, an estimated value of an instantaneous value of a model restriction object amount output by the second dynamic model if it is assumed that the perturbation model manipulated variable is zero, and means for comparing the estimated value of an instantaneous value of the model restriction object amount with the permissible range to determine a restricted restriction object amount that has been restricted to fall within the permissible range on the basis of the comparison, wherein the manipulated variable of the floor reaction force moment is determined 15 on the basis of at least a difference between the instantaneous value of the model restriction object amount determined by the second model calculating means and the 20 25

restricted restriction object amount.

26. The gait generating device of a legged mobile robot according to Claim 20, wherein the means for determining the manipulated variable of a floor reaction force moment 5 comprises means for estimating, on the basis of at least an instantaneous value of a model restriction object amount determined by the second model calculating means and the required value, an estimated value of an instantaneous value of a model restriction object amount 10 output by the second dynamic model if it is assumed that the perturbation model manipulated variable is matched to the required value, and means for comparing the estimated value of an instantaneous value of the model restriction object amount with the permissible range to determine a 15 restricted restriction object amount that has been restricted to fall within the permissible range on the basis of the comparison, wherein the manipulated variable of the floor reaction force moment is determined on the basis of at least the difference between the instantaneous 20 value of the model restriction object amount determined by the second model calculating means and the restricted restriction object amount.

27. A gait generating device for generating a desired gait of a legged mobile robot that travels by moving a 25 plurality of legs extended from its body, comprising:

permissible range setting means for setting a permissible range of a restriction object amount, the

restriction object amount being a vertical component of a floor reaction force moment or a component of the floor reaction force moment in floor surface normal line direction, or a vertical component of an angular momentum changing rate of the robot or a component of the angular momentum changing rate in floor surface normal line direction, to be applied to the robot;

desired floor reaction force provisional instantaneous value determining means for sequentially determining a provisional instantaneous value of at least a desired floor reaction force among a desired motion and a desired floor reaction force constituting the desired gait;

first model calculating means for supplying at least a provisional instantaneous value of the desired floor reaction force to a first dynamic model that indicates a relationship between a motion of the robot and a floor reaction force so as to determine a first provisional instantaneous value of a desired motion as an output of the first dynamic model;

second model calculating means with restriction for supplying at least a provisional instantaneous value of the desired floor reaction force to a second dynamic model that indicates a relationship between a motion of the robot and the restriction object amount so as to determine a second provisional instantaneous value of a desired motion as an output of the second dynamic model such that

an instantaneous value of a restriction object amount substantially balancing with the second provisional instantaneous value of the desired motion on the second dynamic model falls within the permissible range;

5        manipulated variable calculating means for determining a manipulated variable of a floor reaction force moment on the basis of at least a difference between the first provisional instantaneous value and the second provisional instantaneous value of the desired motion such 10      that the difference approximates to zero; and

model input correcting means for additionally supplying the manipulated variable of the floor reaction force moment to at least one of the first dynamic model and the second dynamic model,

15        wherein the second provisional instantaneous value of the desired motion is determined as the instantaneous value of the desired motion.

28. The gait generating device of a legged mobile robot according to Claim 27, wherein the difference between the 20      first provisional instantaneous value and the second provisional instantaneous value of the desired motion includes a difference in a state amount about a vertical axis or about a floor surface normal line axis of the posture of a predetermined part of the robot.

25        29. The gait generating device of a legged mobile robot according to Claim 27, comprising means for determining an instantaneous value of a floor reaction force moment

corresponding to a restriction object amount substantially balancing with an instantaneous value of the desired motion on the second dynamic model as an instantaneous value of a desired floor reaction force moment

5 constituting the desired gait.

30. The gait generating device of a legged mobile robot according to Claim 17, comprising third model calculating means for supplying at least a provisional instantaneous value of the desired floor reaction force to a third dynamic model representing a relationship between a motion of the robot and a floor reaction force so as to determine a third provisional instantaneous value of a desired motion as an output of the third dynamic model, wherein the means for determining a required value of a floor reaction force moment correction amount of the desired floor reaction force determines the required value on the basis of a difference between a desired instantaneous value of the determined desired motion and a third provisional instantaneous value of the desired motion such that the difference approximates to zero.

20 31. A gait generating device for generating a desired gait of a legged mobile robot that travels by moving a plurality of legs extended from its body, comprising:

25 permissible range setting means for setting a permissible range of a restriction object amount, the restriction object amount being a vertical component of a floor reaction force moment or a component of the floor

reaction force moment in floor surface normal line direction, or a vertical component of an angular momentum changing rate of the robot or a component of the angular momentum changing rate in floor surface normal line

5 direction, to be applied to the robot;

desired motion provisional instantaneous value determining means for sequentially determining a provisional instantaneous value of a desired motion constituting the desired gait;

10 model calculating means for supplying the provisional instantaneous value of the desired motion to a dynamic model representing a relationship between a motion of the robot and the restriction object amount so as to determine an instantaneous value of a model restriction object  
15 amount as an output of the dynamic model; and

desired instantaneous value determining means for determining an instantaneous value of a desired motion by correcting the provisional instantaneous value of the desired motion on the basis of a portion of the model  
20 restriction object amount instantaneous value that deviates from the permissible range and that has been passed through a low-pass filter.

32. The gait generating device of a legged mobile robot according to Claim 31, wherein the desired instantaneous value determining means determines a floor reaction force moment corresponding to a difference between the model  
25 restriction object amount instantaneous value and the

deviating portion as the instantaneous value of a desired floor reaction force moment constituting the desired gait.

33. A control device of a legged mobile robot for controlling an operation of the robot to make the robot 5 follow a desired gait generated by the gait generating device of a legged mobile robot according to any one of Claims 1, 14, 27, and 31, comprising:

slippage determining means for determining the occurrence of a slippage of the robot in operation, 10 following the desired gait,

wherein the permissible range setting means variably sets the permissible range according to a determination result of the slippage determining means.

34. The control device of a legged mobile robot 15 according to Claim 33, wherein the slippage determining means determines the occurrence of a slippage on the basis of at least a ground speed of a distal portion of a leg in contact with the ground.

35. The control device of a legged mobile robot 20 according to Claim 33, wherein the slippage determining means comprises means for determining an apparent spring constant of a leg on the basis of at least a temporal changing rate of an actual floor reaction force acting on the leg in contact with the ground and a ground speed of a 25 distal portion of the leg, wherein the occurrence of a slippage is determined on the basis of at least the apparent spring constant.

36. The control device of a legged mobile robot according to Claim 33, wherein the slippage determining means determines the occurrence of a slippage on the basis of at least an actual floor reaction force acting on a leg 5 in contact with the ground that has been passed through a band-pass filter having a frequency pass characteristic in a range near a predetermined frequency.